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Various remeshing arrangements for two-dimensional finite element crack closure analysis

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ABSTRACT

The varying mesh technique avoiding redundant elements has been proved to be computation efficient in finite element crack closure analysis. Because the element model varies every cycle, the calculated information has to be mapped from the old to the new model. The results of this new technique are highly related to the mapped stress quality. In this study, the causes that the mapped stress quality can be improved solely by good remeshing arrangements are studied. A hybrid technique combining the new and conventional techniques is proposed. It is found that this hybrid technique may further improve the calculated results.

1. Introduction

Finite element technique for the computation of plasticity-induced crack closure has been widely investigated for several decades. In the early days, issues regarding the load level [1–3], stress ratio [1–5], plane stress and strain conditions [1,3–11], criteria for opening stress determination [10,12,13], notch plasticity [11,14], variable amplitude loading [15–18], and material law [9,11,19] were studied. In addition, the important effects of element size were also studied for 2D crack closure problems [8,15,20,21]. As the computation efficiency of computers is improved, the researchers pay more attention to the 3D crack closure problems [18,22–30]. Among these 3D analyses, Hou [28] attempted to simulate the crack shape evolution and closure effects simultaneously. The possibility of using a remeshing technique for this type of analysis was mentioned but the technique was not really developed in the study. Gozin and Mehrdad [30] then developed this technique and calculated the interaction between the closure effects and the shape evolution for 3D cracks.

The remeshing technique has been widely investigated in the finite element method. In the finite element metal forming analysis, remeshing has to be performed when the metal is heavily deformed or the analysis of the original model cannot be continued with the ill-deformed domain [31]. Another application of the remeshing technique is the adaptive finite element analysis in which better finite element models of an analyzed domain is automatically generated when the domain has been analyzed with an inferior model [32]. The remeshing technique has also been used in crack problems. Most of these studies were focused on the prediction of crack growing path when the crack was located in a component with complicated geometry [33–35]. This type of analysis usually involved only elasticity without considering the crack tip plasticity.

McClung and Sehitoglu [2,3] studied the effects of some numerical factors that affected the finite element crack closure results and recommended at least ten elements embedded in the crack tip plastic zone so that reliable crack opening stresses could be obtained. This requirement restricts the element size ahead of the crack tip and increases, especially for the 3D

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Nomenclature

Abbreviation

ξ, η	isoparametric coordinates
σ_x, σ_y, σ_{xy}, σ_z	stress components
E_y	approximate y-displacement error of the nearest-tip node
$h(\xi,\eta)$	shape function
n_{CNV}	number of CNV cycles in the hybrid analysis
n_s	number of cycles for shift of element expansion
N	total number of cycles in a closure analysis
r_A	ARNF
R	stress ratio
R_y	ARNF sum
S_{max}	maximum external stress
S_{op}, $S_{op,d}$	crack opening stress and crack opening stress deviation
$S_{op,CNV}$, $S_{op,hybrid}$	crack opening stress of CNV and hybrid techniques
ΔS	stress increment of each load step
u_y	crack face displacement of the nearest-tip node caused by unit load
VM	varying mesh
W	width of the analyzed domain
ARNF	artificial residual nodal force
CEE	coarse element expansion
CNV	conventional
FEE	fine element expansion
FERE	fine element rotating expansion

problems, the total number of elements when the model is used in a crack problem with long distance propagation. This is because numerous fine elements are needed in the region far away from the crack tip so that the McClung and Sehitoglu requirement is still fulfilled when the crack tip propagates to the nearby location of these distant elements. But these fine elements are redundant when the crack tip is far away. As a consequence, for a large portion of the analysis these fine elements only wait for the crack to propagate to the nearby location. With this recognition, Hou [36] proposed a varying mesh (VM) technique in which the concept of remeshing was adopted in 2D crack closure problems to avoid unnecessary fine elements in the distant region. Because numerous fine elements were saved, the computation time was largely reduced, and acceptable opening stresses were still obtained when compared to the results of the conventional (CNV) technique. This is a new application of the remeshing technique in the analysis of crack problems.

In the VM technique, remeshing is performed every load cycle. When the new model is constructed, the state variables of the old model must be mapped to the new model so that the analysis can be continued with the new model. Hou [36] noted that in the new model the residual nodal forces generated from the mapped stresses caused errors in the calculated crack face displacements, and the calculated opening stresses were thus affected. However, these errors could be reduced by various remeshing arrangements and the reasons for this fact were not fully explained in Hou's article. In the current study, more issues regarding the mapped residual nodal forces are supplementally investigated and the causes that the VM results can be improved by remeshing arrangements are explained. In addition, a hybrid approach which is based on the observations of these mapped residual nodal forces is proposed. With this approach the calculated opening stress can be improved without losing the computation efficiency.

2. The varying mesh technique

2.1. New model construction

Fig. 1(a) schematically shows a typical finite element model used in a 2D crack closure analysis. When the analysis of the old model is complete and before the crack tip node is released for a new load cycle, the model is remeshed by horizontally moving all the nodes in the dashed rectangle with a distance identical to the crack growth increment of each cycle, i.e., the horizontal size of the fine element. With this arrangement, the number of fine elements ahead of the crack tip always remains the same after the tip node of the new model is released. As a result, the McClung and Sehitoglu's requirement can be always fulfilled even if the crack is planned to grow a long distance. Because the new model is used for the subsequent